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NASA TM X-68204

EFFECT OF CONTAMINATION ON THE OPTICAL PROPERTIES OF TRANSMITTING AND REFLECTING MATERIALS EXPOSED TO A MMH/N_2O_4 ROCKET EXHAUST

by Robert L. Bowman, Ernie W. Spisz,
and John R. Jack
Lewis Research Center
Cleveland, Ohio 44135

TECHNICAL PAPER proposed for presentation at
Seventh JANNAF Plume Technology Conference
Redstone Arsenal, Alabama, April 3-5, 1973

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National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

ABSTRACT

This paper presents the changes in spectral transmittance, and reflectance due to exposure of various optical materials to the exhaust plume of a 5-pound thrust bipropellant rocket. The engine was fired in a pulsed mode for a total exposure of 223.7 seconds in the NASA Lewis Research Center Environmental Simulator Facility. Spectral optical properties were measured in air before and after exposure to the exhaust plume in vacuum. The contaminating layer resulted in both absorption and scattering effects which caused changes as large as 30-50% for transmitting elements and 15% for mirrors in the near ultraviolet wavelengths. The changes in spectral properties of materials exposed to the exhaust plume for 44 and 223.7 seconds are compared and found to be similar.

E-7373

INTRODUCTION

The optical properties of spacecraft lenses, windows, mirrors, and thermal control coatings can be affected by contamination from sources on the vehicle. The effect of the contaminant will be of concern if spectral absorption or scattering is introduced at critical wavelengths or if the solar absorptance or thermal emittance are changed. Since thin films of some types of contaminants can cause one or more of these effects, information on the contaminant source and the optical effect of the contamination is required. Among the possible sources of such contamination are the thrusters used for attitude control of the spacecraft.

At the Lewis Research Center a liquid-helium cooled space environment facility is available so that thruster contamination studies can be done with proper simulation of space conditions. Previous Lewis studies of contamination from RCS thrusters have been published in references 1, 2, and 3.

The purpose of this test was to determine the changes in spectral transmittance and reflectance of several optical materials due to long (223.7 second) total exposure time to a MMH/N_2O_4 rocket exhaust plume. To evaluate the effect of total exposure time, the results obtained from this test are compared to those from a previous test (ref. 2) with an exposure time of about 44 seconds. Also, results for samples at different pallet locations are presented to determine the influence of location in the plume on the optical property degradation. Other aspects of the contamination experiments are presented in companion papers (refs. 4, 5).

EXPERIMENTAL APPARATUS AND PROCEDURE

Facility. - The experiment was performed in the Lewis Research Center 2 × 4 meter liquid helium cooled space simulation chamber which is described in reference 1. A MMH/N_2O_4 5-pound thrust version of the MOL reaction control system thruster (ref. 1) was used as a source of contamination.

For this experiment the thruster was operated in the pulsed mode with, primarily, a 50-millesecond on time and 100-millisecond off time in a series of 8 pulses. An interval of 7 minutes elapsed between series of pulses. A total firing time of 223.7 seconds (4468 pulses) was accumulated over a period of 49 days of which 16 were actual firing periods. During non-firing periods, the facility remained at vacuum conditions. The thruster firing schedule was dictated primarily by the supply of liquid helium and the storage limitations for the boil-off gas.

The optical samples to be discussed in this paper were mounted on a temperature controlled pallet whose plane was parallel to but displaced 10 cm below the thruster axis. Figure 1 is a schematic drawing showing the relative location of the thruster package, and the location and description of the ten samples which are discussed herein. Sample C-1 is located 10 cm from the nozzle exit plane and sample C-7 is 35 cm from the nozzle exit plane. In addition to the ten pallet samples to be discussed, the pallet consists of 26 other samples which included thermal control coatings for in-situ radiative property measurements (ref. 5), silicon solar cells for determining changes in electrical characteristics with solar radiation, and various materials for compatibility studies. All of the pallet samples are 1-in. in diameter and are mounted with their top surfaces flush with the pallet surface to minimize disturbances to the exhaust flow.

Measurements of the spectral optical properties of the samples were made in air before and after exposure to the exhaust products. After the completion of the thruster firing, the samples were stored at room conditions while the spectral measurements were made. It is recognized that the ex situ measurements may include effects other than those which would be measured in-situ. An in-situ spectral measurement capability was not available for these experiments. However, comparisons of integrated ex-situ spectral measurements for changes in solar absorptance with total measurements made in-situ for white coatings indicated that the total changes determined by the two measurements are similar.

Reflectance Measurements. - Spectral reflectance measurements were made from 0.3 μm to 2.5 μm using a Gier-Dunkle magnesium oxide coated integrating sphere reflectometer (ref. 6) with a lithium fluoride prism monochromator (ref. 7). In this reflectometer, the sample is mounted in the center of the sphere so that both the angular-hemispherical reflectance and the diffuse reflectance can be measured. Angular-hemispherical reflectance measurements are made for an angle of incidence of 15 degrees; diffuse reflectance measurements are made for normal incidence so that the specularly reflected radiation is reflected out the entrance port of the sphere and is not measured. Specular reflectance is calculated as the difference between the angular-hemispherical and diffuse reflectance measurements.

Transmittance Measurements. - Two different instruments were used to make spectral transmittance measurements: (1) the MgO coated integrating sphere that was used for reflectance measurements over the wavelength range from 0.3 to 2.5 μm and (2) a 1 meter, 15° Robin mount ultravolet scanning spectrometer (ref. 8) with a 590 grooves per millimeter grating for measurements over the wavelength range from 0.18 to 0.5 μm. Both measuring systems utilized the sample-in/sample-out technique with the sample located at the inlet slit (or port) of the instrument. These two systems measure two different transmittances. The measurements made with the integrating sphere are hemispherical transmittance in that all of the radiation transmitted through the sample is collected and measured by the integrating sphere. The measurements made with the ultraviolet spectrometer are directional transmittance in that only the radiation transmitted and directed along the optical axis of the 1 meter spectrometer is measured. The difference between the two transmittances is due to scattering effects.

Transmittance of the sample in both systems was measured at the center of the sample. An area of 2 mm by 5 mm was covered in the integrating sphere and an area 0.5 mm by 1.5 cm was covered in the ultraviolet spectrometer.

RESULTS AND DISCUSSION

Photographs. - Figure 2 shows typical photographs of the resulting contamination on a fused quartz sample and a mirror sample taken after the samples were removed from the test chamber. The contamination on the fused quartz sample (fig. 2(a)) appears as discrete colorless droplets which are randomly distributed over the sample surface with uncontaminated areas between the drops. On the mirror sample (fig. 2(b)) the droplets are smaller in size and more uniformly distributed over the complete surface of the sample. The difference in the size and distribution of the contaminant droplest for the two samples can probably be attributed to the different materials, difference in surface finish, or the temperature of the sample during thruster firing. It should also be noted that the droplet distribution on the samples may be affected to some degree by gravity because of the orientation of the pallet. In addition, it is noteworthy that, because of the nonuniformity in the size and distribution of the contamination, any measurement of transmittance and reflectance will be affected by the area being sampled and may not be truly indicative of a total contamination effect.

Transmittance Effects. - The effect of thruster contaminant on the hemispherical and directional transmittance of fused quartz sample L-1 for the 223.7 second exposure is shown in figure 3. Data are not presented for wavelengths greater than 0.6 μm because no change was measured in the hemispherical transmittance at wavelenghts longer than 0.6 μm. At wavelengths less than 0.6 μm degradation occurs over all wavelengths for both the hemispherical and directional transmittance. At 0.32 μm, the approximate transmittance changes are 0.11 and 0.15 transmittance units or 11.6 and 16.0 percent for hemispherical and directional transmittance respectively with changes as large as 35 percent being measured at 0.22 μm for the directional transmittance. The change in the hemispherical transmittance

is due mainly to absorption by the contaminant layer. (There are minor changes in front surface reflection but these are negligible.) It can be seen in figure 3 that at wavelengths less than 0.35 μm, absorption is the predominant effect and at wavelengths greater than 0.40 μm scattering is predominant.

The influence of sample location on contamination effects is shown by the comparison in figure 4. The change in transmittance is shown for four fused quartz samples L-6, L-1, R-1, and C-6. Sample R-1 shows the greatest change in both hemispherical and directional transmittance except for wavelengths below 0.28 μm where samples C-6 shows changes greater than 0.3 which is almost a 50 percent degradation in the uncontaminated transmittance. The variation of the changes in directional transmittance with wavelength for samples R-1 and L-1 are similar (fig. 4(a)). At any given wavelength the change for R-1 is greater than for L-1 indicating possibly more contamination on the right side. The data for sample L-1 and L-6 show about the same change in directional transmittance (fig. 4(a)). The changes in hemispherical transmittance (fig. 4(b)) for samples L-1 and C-6 are also the same. However, this sameness may be coincidence since the angle and distance from the nozzle are different for each sample.

The effect of thruster firing exposure time on transmittance changes is shown in figure 5, where a comparison is made between the transmittance changes for fused quartz sample L-1 and a similar fused quartz sample FQ-A from reference 2. Quartz sample FQ-A had a total exposure time of only 44 seconds (as compared to 223.7 seconds for sample L-1) and was located on the sample pallet in the L-2 position (fig. 1). The changes in hemispherical transmittance for these two samples are similar with sample L-1 showing a slightly greater change (degradation) then sample FQ-A. Sample L-1 also showed greater changes in directional transmittance for wavelengths shorter than 0.32 μm, but sample FQ-A showed larger changes for wavelengths greater than 0.32 μm. These large changes for sample FQ-A in the visible wavelengths are due to scattering as indicated by the small absorption effect which occurs. The general conclusion which can be drawn from the comparison in figure 5 of the changes in hemispherical transmittance for the two different exposure times is that total exposure time longer than 44 seconds has only a slight effect on absorption for wavelengths greater than 0.3 μm.

Reflectance Effects. - Figure 6 shows the hemispherical reflectance of mirror L-5 before and after exposure to the thruster plume. The contaminated mirror reflectance is lower than that obtained for the clean mirror at wavelengths less than 1.5 μm. At 0.6 μm for example the contaminated mirror reflectance is 7.5 percent less than the clean mirror reflectance. The character of the change in mirror reflectance can be seen more clearly in figure 7 which shows the fractional change in hemispherical reflectance for mirrors L-2, L-5, R-2 and R-5. The fractional change is given by the reflectance ratio $(\rho_{clean} - \rho_{contaminated}/\rho_{clean})$. This figure shows that there is an apparent absorption effect (as large as 10 percent) occurring around 0.8 μm which is also the region of aluminum absorption. Since absorption due to contamination was not found at this wavelength on the quartz samples, this effect for the mirrors may be due to an enhancement of the aluminum absorption caused by multiple reflections in the contaminant layer.

The influence of sample location on the contaminating effect can also be seen in figure 7. In the wavelength region between 0.5 and 1 μm, the mirrors R-2 and R-5 show more fractional change in reflectance than the mirrors L-2 and L-5. This is the same trend that was found for the quartz samples and may indicate more contamination on the right side of the pallet. It is also noteworthy that the fractional change is greater for the mirrors which are farther from the thruster nozzle. The mirrors L-2 and R-2, though closer to the nozzle exit plane, are at a larger angle with respect to the thruster axis.

The effect of thruster firing exposure time on reflectance changes is shown in figure 8 by the comparison of the fractional changes in hemispherical reflectance for mirror L-2 exposed for 223.7 seconds and mirror M-A (ref. 2) exposed to the plume for 44 seconds. The results indicate less change in hemispherical reflectance for the longer exposure time than for the shorter but the difference is very slight. This slight difference is consistant with the results found for the quartz hemispherical transmittance comparison discussed previously.

Two samples of 2024-T4 aluminum were included on the pallet to determine the compatibility of this type of aluminum to the exhaust products. The surface on one of the samples was highly polished while the other sample had a diffuse finish provided by glass-bead-blasting the surface. The hemispherical reflectance data for these samples shown in figure 9 shows a significant decrease over the wavelength range covered. The degradation in reflectance is as large as 40 percent for the polished surface and 50 percent for the diffuse surface at a wavelength of 0.4 μm. An integration to obtain solar absorptance for these two surfaces shows an increase of 0.14 and 0.23 which could introduce thermal control problems if such material is used on critical surfaces. The large decreases in reflectance of these materials may possibly be due to chemical effects because the mirror and fused quartz samples do not indicate such large changes due to absorption by the contaminant layer alone.

SUMMARY

The effects on the spectral optical properties for 223.7 seconds of exposure to the exhaust products from a MMH/N_2O_4 5-pound thruster were evaluated for several prospective spacecraft materials. Degradation effects for both reflectance and transmittance were measured on the ten samples that were studied.

The decrease in fused quartz directional transmittance was due to both absorption and scattering effects with absorption predominant in the near uv wavelengths and scattering being predominant in the visible wavelengths. Changes as large as 30 to 50 percent were measured in the near uv wavelengths with negligible changes in hemispherical reflectance being measured in the near infrared. A comparison of the changes for various samples on the sample pallet indicated a larger effect for samples on the right side of the engine centerline.

Changes in angular-hemispherical reflectance of up to 15 percent in the near ultraviolet were measured together with 3 to 5 percent changes throughout the visible. In the region of 0.8 μm, changes in reflectance as much as 10 percent were measured.

The effect of total exposure time was determined by comparing the results of a quartz and mirror sample from this experiment (223.7 seconds) with the results of a previous experiment (44 seconds). The comparison indicated that total exposure time greater than 44 seconds had only a very slight influence on absorption effects for both the hemispherical transmittance and reflectance measurements for the wavelength range above 0.3 μm.

REFERENCES

1. Cassidy, J. F.: Space Simulation Experiments on Reaction Control System Thruster Plumes. Paper 72-1071, AIAA, Nov. 1972.

2. Jack, J. R.; Spisz, E. W.; and Cassidy, J. F.: The Effect of Rocket Plume Contamination on the Optical Properties of Transmitting and Reflecting Materials. Paper 72-56, AIAA, Jan. 1972.

3. Sommers, R. D.; Raquet, C. A.; and Cassidy, J. F.: Optical Properties of Thermal Control Coatings Contaminated by MMH/N_2O_4 5-Pound Thruster in a Vacuum Environment Simulator. Thermal Control and Radiation. Vol. 31 of Progress in Astronautics and Aeronautics. Chang-Lin Tien, ed., MIT Press, 1973, pp. 145-158.

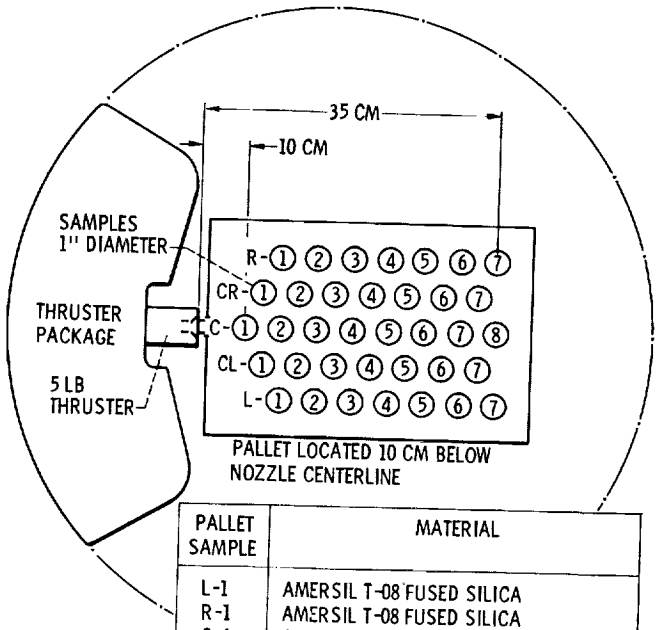
4. Spisz, E. W.; Bowman, R. L.; and Jack, J. R.: Effects of a Bipropellant Thruster Plume on Spacecraft Materials and Optical Components. Presented at the 7th JANNAF Plume Technology Conference, Redstone Arsenal, Alabama, Apr. 3-5, 1973.

5. Sommers, R. D.; and Raquet, C. A.: Effect of Thruster Pulse Length and Thruster Exhaust Damage of S-13G White Coatings. Presented at the 7th JANNAF Plume Technology Conference, Redstone Arsenal, Alabama, Apr. 3-5, 1973.

6. Edwards, D. K.; Gier, J. T.; Nelson, K. E.; and Roddick, R. D.: Integrating Sphere for Imperfectly Diffused Samples. J. Opt. Soc. Am., vol. 51, no. 11, Nov. 1961, pp. 1279-1288.

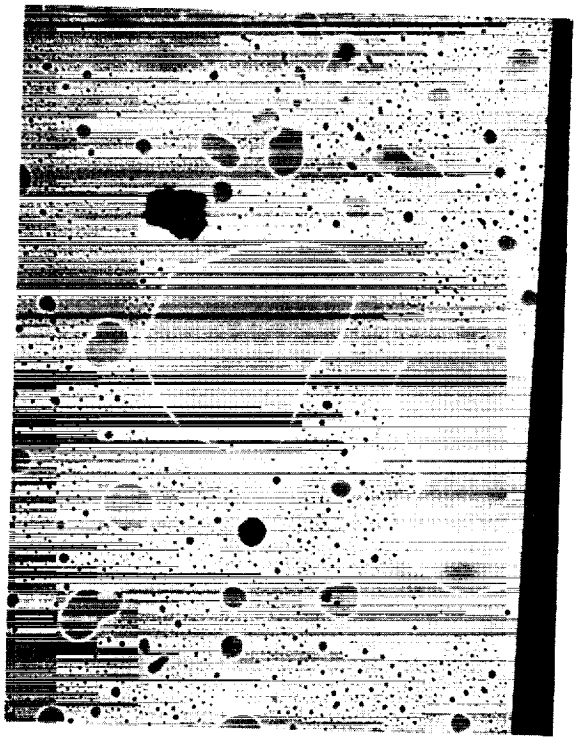
7. Anon.: Instruction Manual - Perkin Elmer Infrared Equipment. Vol. 3A Perkin Elmer Corp., Norwalk Conn., 1956.

8. Anon.: Model 78-731, 1 meter, 15° Robin Mount Vacuum Ultraviolet Scanning Spectrometer. Engineer Publ. No. 78-751, Jarrell-Ash Co., Waltham, Mass., July 1966.

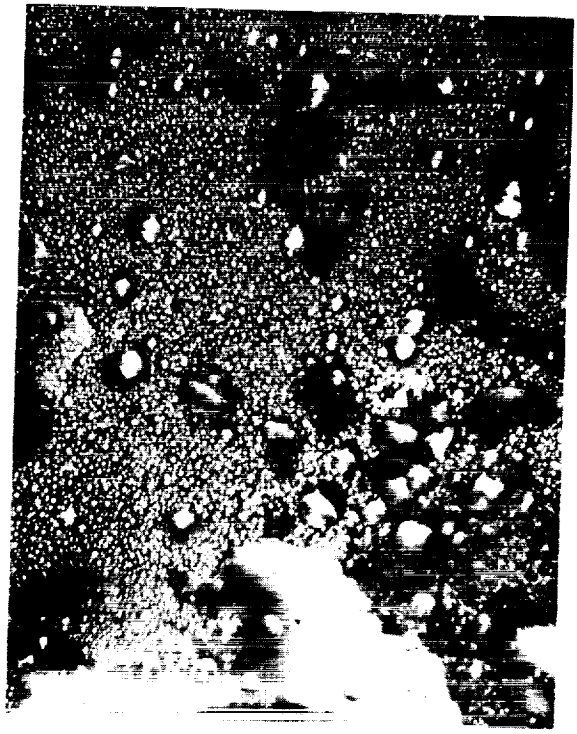


PALLET SAMPLE	MATERIAL
L-1	AMERSIL T-08 FUSED SILICA
R-1	AMERSIL T-08 FUSED SILICA
C-6	AMERSIL T-08 FUSED SILICA
L-6	CORNING 7940 FUSED QUARTZ
R-2	SiO OVERCOATED ALUMINIZED MIRROR
R-5	SiO OVERCOATED ALUMINIZED MIRROR
L-2	SiO OVERCOATED ALUMINIZED MIRROR
L-5	SiO OVERCOATED ALUMINIZED MIRROR
CR-2	POLISHED 2024-T4 ALUMINUM
CR-1	MATTE FINISH 2024-T4 ALUMINUM

Figure 1. - Sample pallet layout.

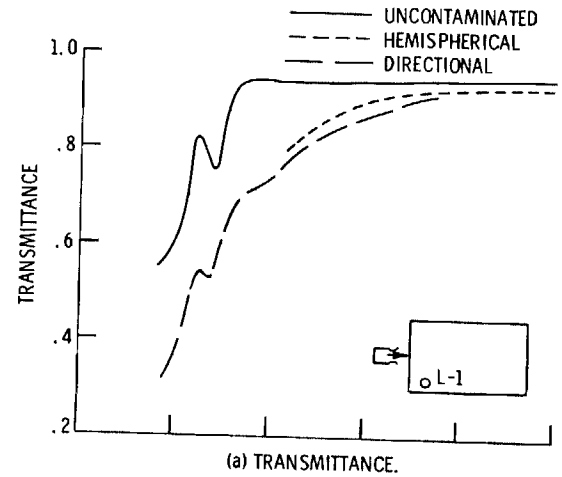


(a) FUSED QUARTZ SAMPLE L-1.

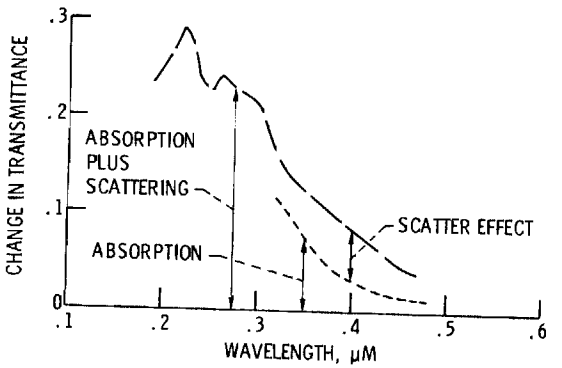


(B) MIRROR SAMPLE L-2.

Figure 2. - Photomicrographs of contaminated samples. Magnification, X100.

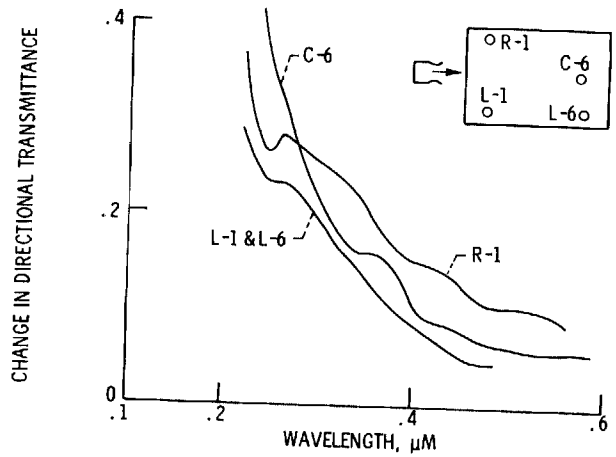


(a) TRANSMITTANCE.

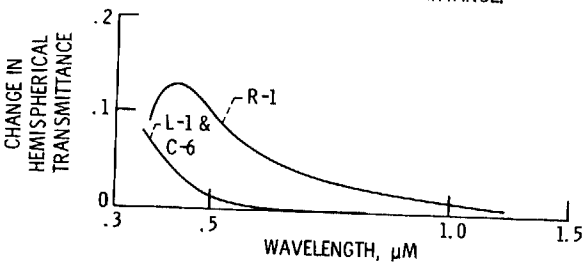


(b) CHANGE IN TRANSMITTANCE.

Figure 3. - Effect of thruster contamination on the transmittance of fused quartz sample L-1.



(a) DIRECTIONAL TRANSMITTANCE.



(b) HEMISPHERICAL TRANSMITTANCE.

Figure 4. - Effect of sample location on change in transmittance.

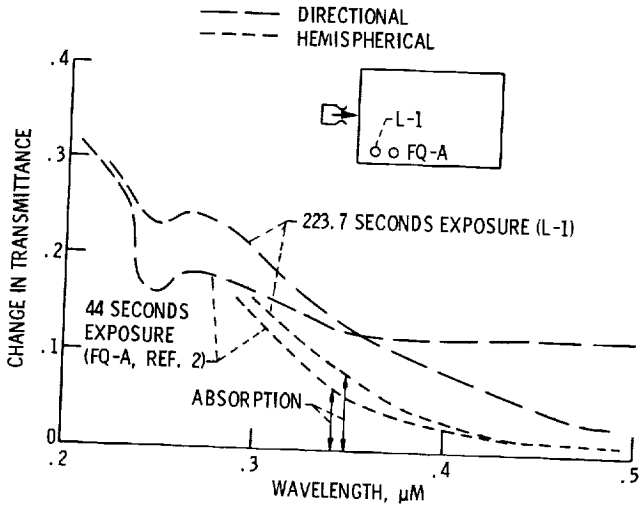


Figure 5. - Effect of thruster firing exposure time on transmittance changes.

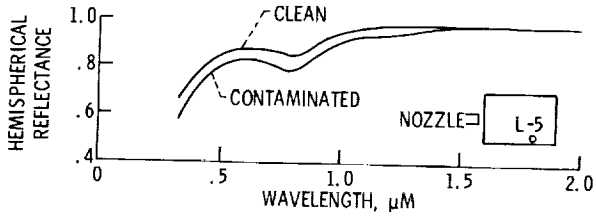


Figure 6. - Effect of thruster contamination on the hemispherical reflectance of mirror L-5.

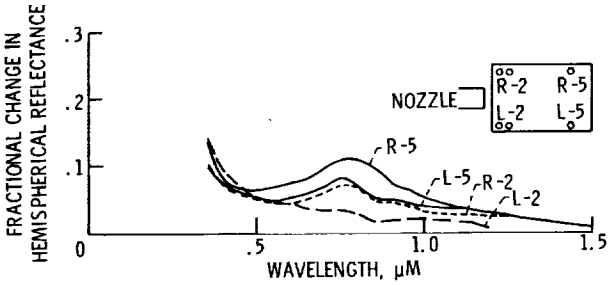


Figure 7. - Fractional change in reflectance of mirrors R-2, R-5, L-2, and L-5 due to thruster contamination.

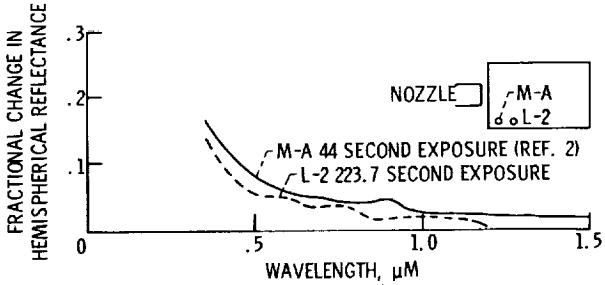
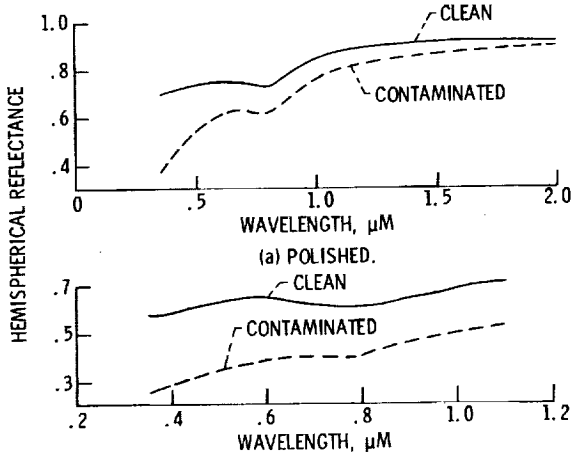


Figure 8. - Effect of thruster exposure time on fractional reflectance changes.



(b) GLASS-BEAD BLASTED (MATTE FINISH).

Figure 9. - Hemispherical reflectance of 2024-T4 aluminum.